Development and Validation of a Mobile, Autonomous, Broadband Passive Acoustic Monitoring System for Marine Mammals

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LONG-TERM GOALS

Our long-range objective is to understand the oceanographic processes that influence the distribution of whales in the ocean. In support of this objective we seek to develop a fully-integrated autonomous acoustic observing system capable of detecting and classifying a wide range of marine mammal vocalizations (from blue whales to beaked whales; 10 Hz – 100 kHz) with proven performance. This work will ultimately improve our ability to predict whale distribution and bolster efforts to mitigate human impacts on marine mammals. Long-endurance oceanographic sampling platforms such as gliders and profiling floats provide a new opportunity for acquiring acoustic signals from marine animals with immediate applications in conservation and mitigation.

APPROACH

High-endurance autonomous platforms have tremendous potential for persistent monitoring of the ocean environment, including ambient noise and marine mammal vocalizations. We have previously demonstrated the utility of such platforms by simultaneously collecting passive acoustic recordings, environmental measurements, and prey observations from a fleet of ocean gliders. In contrast to these studies, which resulted in recorded audio data that were analyzed weeks after collection, many applications require almost immediate data return to facilitate at-sea decision making. To meet this

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14. ABSTRACT
Our long-range objective is to understand the oceanographic processes that influence the distribution of whales in the ocean. In support of this objective we seek to develop a fully-integrated autonomous acoustic observing system capable of detecting and classifying a wide range of marine mammal vocalizations (from blue whales to beaked whales; 10 Hz ? 100 kHz) with proven performance. This work will ultimately improve our ability to predict whale distribution and bolster efforts to mitigate human impacts on marine mammals. Long-endurance oceanographic sampling platforms such as gliders and profiling floats provide a new opportunity for acquiring acoustic signals from marine animals with immediate applications in conservation and mitigation.

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need, the autonomous platform must be able to acquire and rapidly process acoustic data on board, detect and classify marine mammal vocalizations, and telemeter a summary of those detections to a ship- or shore-based station.

There is a wide variety of instrumentation and software available for collecting and analyzing marine acoustic data; however, most existing tools are optimized for either low or high frequency applications. While this is acceptable for researchers focusing on particular taxa, most conservation and mitigation efforts must address the needs of a broad range of species. For example, some species of beaked whales may be especially sensitive to active sonar while certain baleen whales are at risk from ship strikes, yet there is no single instrument capable of monitoring both taxa simultaneously from a variety of autonomous platforms (gliders, floats, drifters, moorings). We are therefore working to develop a low-power digital monitoring instrument that is capable of long-term autonomous detection and classification of vocalizations over the frequency range encompassing most marine mammals.

The system will be based on a new self-contained, low-power digital acoustic monitoring device (D-MON) currently in prototype development at WHOI. We will integrate the D-MON in commercially-available gliders, profiling floats, and surface drifters to create a fleet of persistent real-time acoustic monitoring platforms. In parallel, we will develop acoustic detection and classification algorithms to identify two critical classes of marine mammals: low-frequency baleen whales (e.g., right, fin, humpback whales), and high-frequency beaked whales. The performance of these detectors will be verified at several field sites with the opportunity for independent ground-truth. The work will result in a modular, open-source, acoustic detector capable of installation on a wide variety of autonomous platforms, together with an understanding of how to use these platforms to maximize detection performance in fleet-relevant monitoring tasks.

This project encompasses three major efforts: detector design, implementation and field verification.

<u>Detector design</u>: Successful detector design requires a knowledge not only of the properties of the signals to be detected but also of the environment and behavior of the animals that produce them. Our approach is an integrated one in which detector design is directly informed by observations from on-going field studies. This focuses attention on the real conditions in which an autonomous detector has to operate, e.g., fluctuating ambient noise and frequent interference from non-target species. We are thus creating detection methods that are robust, extensible and verifiable from the outset.

<u>Implementation</u>: Detector algorithms will be implemented in real-time on the D-MON, a low-power self-contained acoustic signal processing device developed at WHOI. This device has been created specifically for passive acoustic detection and so has the necessary broadband, low-noise signal acquisition capabilities. The device will be integrated in profiling floats and gliders to create a persistent detection capability. As detection algorithms mature, they will be ported to the D-MON for autonomous operation. All elements of the D-MON design will be made openly available to the community under a share-alike license. This ensures that new developments do not remain proprietary will still providing recognition for contributions. We believe that this open approach is the best and most efficient way to obtain community-accepted, verifiable and inter-operable methods for passive acoustic monitoring. Initially, D-MONs will be fabricated at WHOI and will be an orderable item. If sufficient orders are received, production will be transitioned to a turn-key contractor in the short-term and we will seek an alliance with an oceanographic instrument producer in the long-term.

Verification: Our detectors will be verified in two ways. First, signals from known species recorded in the field will be used for bench verification of algorithms and implementations. Complete autonomous systems will then be tested in the field using D-MON to simultaneously detect and record sound. This allows performance and missed detects to be evaluated after each trial. For beaked whales, field testing will take place off the island of El Hierro in the Canary Islands, a site with coastal resident populations of Blainville's beaked whale, Mesoplodon densirostris, and Cuvier's beaked whale, Ziphius cavirostris. This site is unique in supporting simultaneous visual and acoustic observations of these rare species with low-cost shore-based operations. Baleen whale validation will be pursued in the northeastern U.S. in the vicinity of Cape Cod and at other locations as opportunities arise.

WORK COMPLETED

DMON hardware and software

The DMON is a small self-contained acoustic detector/recorder. The device monitors up to three hydrophone channels and records sound to solid-state memory either continuously or when a detection is made. The on-board processor is capable of running multiple detection and classification algorithms simultaneously. The three input channels can be configured for wide-band (blue whale to porpoise) monitoring or for direction finding of signals in a narrower band. Compared to a PAM implementation using off-the-shelf hardware, the DMON design offers several advantages:

(1) power consumption is <10% of what an embedded PC requires for the same computation rate. This translates into longer deployment lifetimes on platforms such as gliders with limited hotel load.

(2) the DMON is specifically designed for low noise sound acquisition. It produces very little electrical noise enhancing its capability to detect weak signals from distant animals.

(3) the DMON is much smaller than an off-the-shelf solution making it straightforward to install in a variety of platforms.

Disadvantages of custom devices like the DMON are their complex and non-portable software, and lack of availability to other researchers. We are addressing these issues as follows. We have developed a software infrastructure which provides a familiar programming environment for scientific programmers. We propose here to continue this effort by developing a software interface for the DMON in the popular open-source PAMGUARD software. The software and hardware design will be openly available and devices will be purchasable at relatively low cost from the Woods Hole Oceanographic Institution (WHOI). Our vision is that the DMON form a reference design for the rapidly expanding field of passive acoustic monitoring.

Vehicle integration

We have integrated the DMON into two low-power platforms capable of persistent monitoring: the Webb Research Corporation's Slocum glider and APEX profiling float. External hydrophones for both platforms provide 10Hz-60kHz monitoring. Serial communications with the vehicle controllers allow near-real-time feedback of detections via Iridium. A drifting surface float with a cabled array of DMONs has also been developed to facilitate rapid field evaluation of detection and tracking algorithms. The three platforms provide the capability to work over a wide range of spatial and temporal scales. We are learning how to best exploit this capability by field evaluation in several different contexts including studies of beaked whales and baleen whales.

Detector/classifier development
We are developing detection and classification software for baleen whale calls and beaked whale clicks taking advantage of extensive sound data holdings at WHOI. The baleen whale detector involves pitch tracking followed by attribute extraction and classification by quadratic discriminant function analysis. The beaked whale detector incorporates discrimination of dolphin clicks based on spectral and click-rate cues. We are currently porting both detectors for real-time operation on the DMON and are evaluating the detection range of the beaked whale detector using sound recordings made by DMONs of whales tagged with the WHOI DTAG acoustic recording tag (Johnson & Tyack, 2003). The baleen whale detector incorporates pitch tracking and linear discriminant function analysis.

RESULTS

Working with Dr. Zimmer of the NATO Undersea Research Center, and other partners on a related NOPP project, we completed a simulation study of acoustic detection applied to beaked whales (Zimmer et al., 2008). The simulation included operational characteristics (number of hydrophones, duration of observation, depth of platform), sound source characteristics (vocal output, beam pattern and whale movements), and environmental characteristics (ambient noise levels and sound propagation). We concluded that beaked whales should be detectable acoustically with high probability at up to 3 km from a fixed hydrophone in an environment with fairly low ambient noise. The method allows performance in other environments and with other platforms to be predicted. In particular, the simulation predicts the effective detection swath of slowly-moving platforms such as gliders and profiling floats.

Autonomous acoustic monitors need to both detect and classify the originating species of signals. This requires knowledge of the variety of vocalizations produced by the species of interest (which may vary by location and season) and this knowledge must be condensed into rules for accepting or rejecting sounds. For beaked whales, such rules will be based on the click spectrum (Zimmer et al., 2005; Johnson et al., 2006) and/or the inter-click-interval. For frequent interference sources such as dolphins that are not of interest in themselves, a more efficient approach is to include discrimination in the detector itself. Working with Aarhus University in Denmark, we have developed a discriminating detector based on a bank of template filters spanning both non-target and target sounds. The detector accepts a signal when the output of the target filters exceeds that of the non-target filters by a predetermined amount. We used Monte Carlo simulation fed by real clicks waveforms to determine the probability of detecting a beaked whale click as a function of signal-to-noise ratio (SNR) under different discrimination criteria (Fig. 1). Increased discrimination comes at the expense of a reduced detection probability especially at low SNR. Nonetheless, the new detector rejects a high proportion of dolphin clicks at moderate SNR with little loss in beaked whale detections and is straightforward enough for real-time implementation in an autonomous detector such as the DMON.

RELATED PROJECTS

We are funded by ONR in an NOPP project focused on exploring the potential and performance of passive acoustic detection for deep-diving toothed whales, in particular beaked whales. This is an integrated study examining the relationships between sound production and behavior, habitat use, group size and environmental correlates. There is considerable synergy between the NOPP project and the current program, and many results directly benefit both programs. Whereas the current project is focused on implementation and field verification of detectors, the NOPP project is concerned with uncovering the underlying factors that determine the performance of acoustic detectors for toothed

whales. Results from the NOPP project will help improve detector design, will produce signals for verification, and will aid in interpreting results from the current program.

Initial development and validation of baleen whale detectors is supported under a companion ONR program “Detection and Classification of Baleen Whale Vocalizations from Autonomous Platforms.”

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